Nature inspired wet adhesive E-Skin patch for biosensing applications

Ashis Tripathy[1*], Vipin Richhariya[1], Narayan Sahoo[1], Filipe Samuel Silva[1]

[1]Centre for Micro-Electro-Mechanical Systems (CMEMS), University of Minho, Campus de Azurém, 4800-058, Guimarães, Portugal
Corresponding author: ashisbidyarthi@gmail.com (A. Tripathy)

Abstract:

Tree frogs are able to climb or stick to wet and rough surfaces. The hexagonal epithelial cells enclosed by profound passages which shield the surface of each toe pad and the array of nano-pillars on their surface are the main reason for their outstanding reversible adhesion in wet and rough environment. Inspired by the frog toe pad hexagonal hierarchical micro-pillars are developed by using Silicon rubber/ZrO_2 nanocomposite. Due to the addition of oxide nanoparticles wettability properties of the rubber enhanced. The interlocking structures and hexagonal pattern helps to improve the capillary action and the sweat/water particles are drained easily, as a result surface adhesion increases. To design the hexagonal micro-pillars innovative laser engraving technique is adopted. The homogeneous distribution of nanoparticles and hierarchical hexagonal micro-patterns are confirmed through SEM analysis. This innovative design approach is helpful to design E-skin adhesive wearable devices for accurate monitoring of physiological signals.

Keywords: Bio-inspired, biosensing, hexagonal micro-pillars, wet adhesion, adhesive E-skin, nanocomposite.

1. Introduction

Skin adhesive wearable sensing devices are becoming more and more popular in recent years. Proper adhesion to the skin surface is highly essential to detect minute physiological signals. In order to improve the adhesion with skin surface the adhesive patch must gutter air and water particles between the patch and the skin (Laulicht, Langer, and Karp 2012). There are numerous bio-inspired skin adhesive patches with different geometry/patterns, like mushroom-shaped tips, (Kim et al. 2016, Drotlef et al. 2017, Kizilkan and Gorb 2018) micro-needles (Wang, Pastorin, and Lee 2016) and micro-grooves (Rao et al. 2018) are developed. However, these patches are not adhered properly to wet skin. In recent times, amphibians like tree frogs are drawing human attention due to their outstanding adhesion and locomotion on both dry and wet adhesive surfaces. (Langowski et al. 2018, Federle et al. 2006) Various researchers are tried to mimic the frog pad pattern to improve adhesion for relatively flat and rough surfaces in dry/wet conditions. Nevertheless, the fundamental principles of amphibious adhesion, i.e. the increased omnidirectional peeling resistance due to drainage of water molecules and the unique geometry of the hexagonal building matrix to rough and wet surfaces, are not yet fully explored.

This study highlights the design architecture of tree-frog toe pad inspired adhesive skin patch with hierarchical hexagonal micro-patterns. The laser engraved bio-inspired unique hexagonal structured flexible patch will be highly beneficial for skin adhesive wearable devices to sense minute physiological signals.

2. Materials and Methods

Silicone rubber (Si) and zirconium oxide (ZrO_2) are used as raw material to fabricate the bio-inspired adhesive patch. Initially, the quantity of ZrO_2 ceramic nanopowder is optimized with the Si to produce highly flexible thick film. After optimization, the Si@ZrO_2 patch is blended for 45 min to distribute the ceramic nanoparticle throughout the surface. After blending, the composite polymeric sheet is vulcanized for 2 hrs by using hot compression molding machine at a temperature of 230 °C. Finally, hexagonal micro-patterns are developed by using Nd:YAG Laser (P_{max}~10 W and spot diameter ~ 6 μm) on vulcanized polymeric sample. The synthesis of nanocomposite and formation of frog toe inspired hexagonal micro-pillars are graphically illustrated in Fig. 1(a). The morphological analysis of laser engraved hexagonal patterns is confirmed by using scanning electron microscope (SEM). Water contact angle (WCA) of the bio-inspired patch is measured using sessile contact angle meter. Flexibility is tested by using universal testing machine.

3. Results and Discussion

Uniform distributions of ceramic nanoparticles are confirmed from the SEM analysis. Incorporation of ceramic nano-powder improves the hydrophilic properties of Silicon rubber. The photograph of tree-frog toe and its SEM images are illustrated in Fig. 1b (i-ii). Laser engraved hexagonal patterns are clearly observed in SEM images as shown in Fig. 1b(iii-v). The space between each hexagonal pattern forms channel to drain sweat/water droplets. The laser engraved trade patterns create capillary effect by absorbing sweat/water droplets. The hexagonal micro-patterns act like a suction cup and help to attach with the skin surface. The laser engraved hexagonal micro-channels with optimized geometry is highly useful for omnidirectional reversible adhesion in both dry and wet environment. The flexible path shows excellent flexibility and durability over a long period of compression and relaxation.

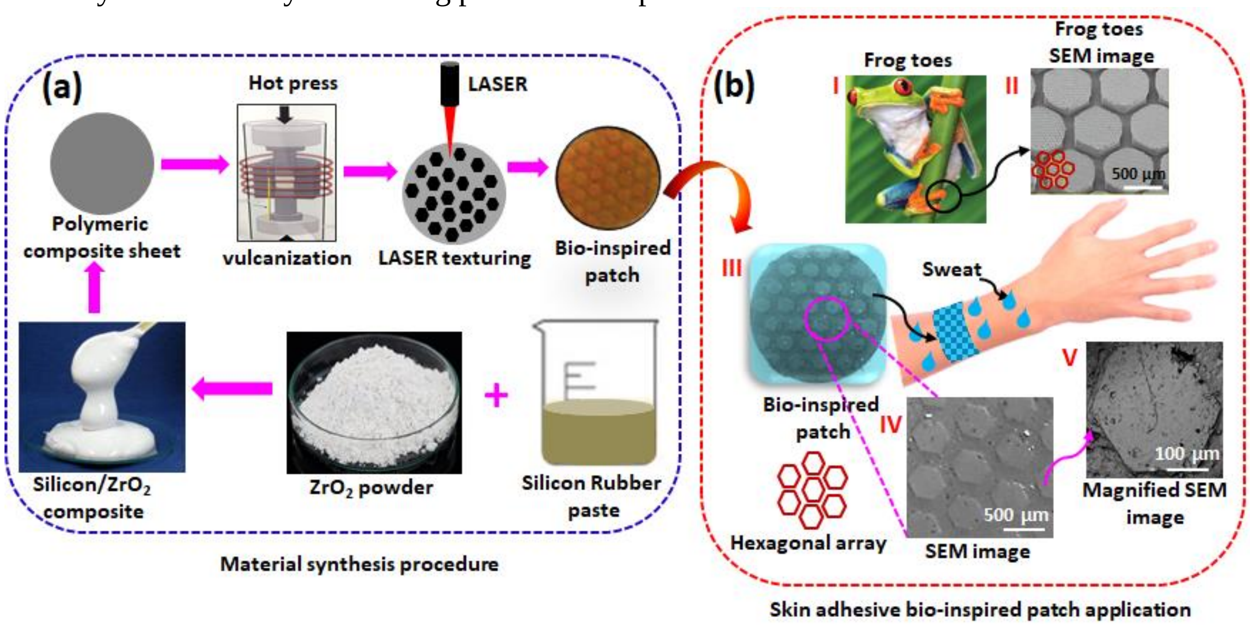

Fig.1. Bio-inspired skin adhesive path. (a) Synthesis procedure of the adhesive patch. (b) Application of adhesive path on skin surface (i-photograph of tree-frog toe, ii-SEM image of frog toe, iii-photograph of bio-inspired adhesive patch, iv-SEM image of bio-inspired path, v-magnified SEM image).

4. Conclusions

Inspired by the tree-frog toe, $Si@ZrO_2$ nanocomposite based flexible patch for dry/wet adhesive E-Skin application is designed. We mimic the hierarchical hexagonal pattern of frog toe by using innovative laser engraving technique. The design geometry and hierarchical distribution of bio-inspired hexagonal patterns are confirmed through SEM analysis. Homogeneous distribution of ceramic nanoparticles on the surface of Si is prominently observed. The design architecture of hexagonal pattern helps to drain the sweat/water particles and act as a suction cup to attach on the skin surface. The space between the hexagonal micro-patterns insists the capillary effect to improve the skin adhesion. The biocompatible materials in the adhesive path don't create any harm to the skin. The adhesive patch shoes excellent flexibility and good durability over multiple compression and relaxation cycles. The unique suction feature and highly water drainable ability of the bio-inspired patch will be useful for adhesive E-skin sensing devices to monitor various physiological signals.

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References

Drotlef, Dirk-M, Morteza Amjadi, Muhammad Yunusa, and Metin Sitti. 2017. "Bioinspired composite microfibers for skin adhesion and signal amplification of wearable sensors." *Advanced materials* no. 29 (28):1701353.

Federle, W, WJP Barnes, W Baumgartner, P Drechsler, and JM Smith. 2006. "Wet but not slippery: boundary friction in tree frog adhesive toe pads." *Journal of the Royal Society Interface* no. 3 (10):689-697.

Kim, Taehoon, Junyong Park, Jongmoo Sohn, Donghwi Cho, and Seokwoo Jeon. 2016. "Bioinspired, highly stretchable, and conductive dry adhesives based on 1D–2D hybrid carbon nanocomposites for all-in-one ECG electrodes." *ACS nano* no. 10 (4):4770-4778.

Kizilkan, Emre, and Stanislav N Gorb. 2018. "Combined Effect of the Microstructure and Underlying Surface Curvature on the Performance of Biomimetic Adhesives." *Advanced Materials* no. 30 (19):1704696.

Langowski, Julian KA, Dimitra Dodou, Marleen Kamperman, and Johan L van Leeuwen. 2018. "Tree frog attachment: mechanisms, challenges, and perspectives." *Frontiers in zoology* no. 15 (1):1-21.

Laulicht, Bryan, Robert Langer, and Jeffrey M Karp. 2012. "Quick-release medical tape." *Proceedings of the National Academy of Sciences* no. 109 (46):18803-18808.

Rao, Ping, Tao Lin Sun, Liang Chen, Riku Takahashi, Gento Shinohara, Hui Guo, Daniel R King, Takayuki Kurokawa, and Jian Ping Gong. 2018. "Tough hydrogels with fast, strong, and reversible underwater adhesion based on a multiscale design." *Advanced Materials* no. 30 (32):1801884.

Wang, Hao, Giorgia Pastorin, and Chengkuo Lee. 2016. "Toward self-powered wearable adhesive skin patch with bendable microneedle array for transdermal drug delivery." *Advanced Science* no. 3 (9):1500441.